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# Energy impacts of the smart home – conflicting visions

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## Keywords

alternative energy systems (AES), savings potential, homes, consumers, energy consumption, smart metering, everyday life, practices, sustainable development, energy saving technologies, advanced metering, information and communication technologies (ICT)

## Abstract

To support the transition towards an energy system that is based 100 percent on renewable energy sources, the smart grid is presently undergoing rapid development in Denmark – a hype that can also be seen in the rest of the world. Many actors are playing in the field, and the present situation is characterized by great uncertainty as to the direction of the development. The paper focuses on the role of households in the smart grid visions proposed by a broad range of stakeholders. It has two aims: first, to sort out the threads of the discussion; what visions are formulated regarding the role of households in the smart grid? What visions are articulated for the functionalities of the smart home? Secondly, we critically investigate these visions to explore if they support the development of sustainable energy consumption.

We claim that the smart home in the smart grid is the latest addition to a family of ideas emerging in relation to the application of information and communication technologies (ICT) in the home. The smart home is thus a melting pot of such different trends as automation of household chores, entertainment and energy management. These different ingredients of the melting pot co-evolve, we argue, and we suggest that the co-evolution may well have negative consequences for the overall energy impact of the transition. The smart grid could become a dynamic that constructs and normalizes new energy-demanding practices and facilitates escalating expectations to comfort. This paper only begins the exploration of the reported discussions; much more research in this area needs to be done.

## Introduction

Interest in smart grids and smart homes has risen dramatically in the last few years. The hype surrounding this prospective revolution in energy systems is seen worldwide, for instance in the 3.4 billion dollars that the Obama administration in USA recently set aside for smart grid R&D, or in Europe's dedication to smart grid research in the Seventh Framework Programme. Also China has jumped on the bandwagon and announced in May 2009 an aggressive framework for smart grid deployment.

For the IT sector, the smart grid is being highlighted as one of the big opportunities for using information and communication technologies (ICT) in addressing climate change and subverting IT's hitherto dominantly negative impacts on energy consumption in e.g. households (The Climate Group 2008).

Modernizing the electrical grid with digital technologies also holds promises for other stakeholders worldwide, such as the energy sector. In the USA, the smart grid discussion is mainly concerned with avoiding brownouts and blackouts in an electricity grid that is strained in periods of peak-demand, whereas the theft of electricity and ICT surveillance of the grid is a concern in e.g. Malta and India (Tornbjerg 2010). In most parts of the world, however, the smart grid is under all circumstances considered an important part of a sustainable transition of the energy system.

In this paper, we are concerned with the Danish discussion, which mainly focuses on the growing integration of wind energy. For the Danish system, the socio-economic benefits of integrating more fluctuating renewables depend on a better utilization of wind power by Danish consumers, through intelligent management of their increased electricity consumption. Recently, the Danish Minister for Climate and Energy mobilized a 'smart grid network' to work on recommendations for how Denmark should future-proof the electrical grid to handle up to 50 percent renewable energy, mainly wind, by 2020.

The present situation is characterized by great uncertainty regarding the future direction of the development. Many stakeholders are showing marked interest in this field and the last few years have featured countless conferences, seminars, meetings, reports and white papers concerning the future of the smart grid in Denmark. The discussion is becoming even muddier, since the field is a meeting place for such diverse sectors as the electricity sector, the transport sector, the IT sector, the housing sector and the district heating and heat pump sector, which are all pulling in different directions and trying to negotiate the character of the transition.

Households are often conceptualized as smart homes in the smart grid, and different visions about the future role of households in the smart grid are part of the discussion.

The purpose of this paper is first of all to sort out the main threads of the discussion: What visions are formulated regarding the role of households and the functionality of the smart home? Secondly, we critically investigate these visions: Will the visions actually support the dynamic that is necessary for a transition towards more sustainable energy consumption? Will the development of the smart home potentially contribute to enhanced energy consumption?

The paper is based on reports and other publications on the smart grid and the smart home, as well as participation in meetings, seminars and conferences. Also, semi-structured, unstructured and informal interviews have been conducted with relevant actors in the energy, IT and housing sectors as well as in public sector organizations.

The research object for this paper – the smart home in the smart grid – is only the latest contribution to a long history of different understandings of what the smart home is. To contextualise the present discussion, the paper starts with a brief presentation of the history of the smart home. The visions of the smart grid, as the framework for the smart home, are then discussed, followed by an overview of the role households and the smart home should play in the smart grid. In relation to this overview, we also present some of the discussions and disagreements relating to the role that the visions ascribe to consumers. Finally, we argue that the smart home is a melting pot of different trends and that the smart-home-in-the-smart-grid co-evolves with these other trends. This co-evolution can potentially have negative consequences for energy consumption.

## The smart home in a historical perspective

The smart home in the smart grid can be seen as the latest addition to a family of ideas emerging in relation to the application of ICT in the home. The concept of the smart home is thus just one among many belonging to a large group of concepts such as the smart house, the electronic cottage, home automation, the networked home, the intelligent home, and the digital home (Miles 1991, Berg 1991).

The introduction of microelectronics offers inexpensive and powerful information processing that can be used to monitor, manage and manipulate in a multitude of consumer products – to interconnect various items of domestic equipment within the home, and to manage systems in the home from a distance. This technological potential opens business opportunities, and from the 1980s this potential was increasingly explored in various smart house projects, used as test beds for innovative ideas (e.g. in 1984, the US Smart House Project was launched by the National Association of Homebuilders, Miles 1991: 68). Over time, new ideas were developed, but some lines of exploration have been remarkably stable.

As illustrated in Figure 1, the smart home can be seen as a melting pot where different trends meet, influence each other, and sometimes merge

Most of the ingredients have quite a long history, and for each of them, new elements and trends have been added along the way. Just a few words on the main ingredients:

*Automation of household chores (home automation)*: Mechanization of household chores was on the agenda long before the emergence of ICT, in relation to the introduction of the small electromotor. The motor could replace muscular strength and transmit energy for heating and cooling, and it was integrated in a wide range of domestic appliances – vacuum cleaner, refrigerator, washing machine, dishwasher, air conditioning etc. Microprocessors add a dimension by replacing or enhancing brain capacity – the ability to calculate, manage, communicate, and regulate – which can be used for increased automation of household chores and for managing them from a distance. Examples are the vacuum cleaner robot and automatic feeding systems for pets, but many more ideas belong to the future.

*The safe and secure home*: Combined with sensor technologies, ICTs make alarm and security functions possible – fire alarm (which can even unlock doors and call the fire brigade), burglar alarm, video door phone, monitoring water leakage alarm. Automatic management of lighting and television can make the house look inhabited when the residents are not at home.

*Home systems management and energy savings*: Energy systems in the home – heating, ventilation and air conditioning systems – can be managed automatically, for convenience and comfort. Increasingly, energy savings are emphasized as a central aim for energy systems management, for instance, by changing the temperature over the day according to needs. Also the lighting system can be managed for energy savings by the use of motion sensors to turn off the lights. The introduction of smart metering has added an extra dimension to energy savings in the smart home, since the provision of quick and visible feedback to consumers on their energy use is expected to encourage savings. Experiences with smart metering and feedback have already been the subject of much research (e.g. Darby 2008, Darby 2010, Hargreaves et al. 2010, Fischer 2008). The most successful examples seem to combine frequent information over a long time period with an appliance-specific breakdown, a clear and appealing presentation and the use of interactive tools (Fischer 2008).

*Home entertainment*: Individual entertainment devices – radio, television, music centre, video game console – have a long history, whereas networked entertainment systems are more recent additions that are advertised as a core element in the digital home. Devices are often connected through the home

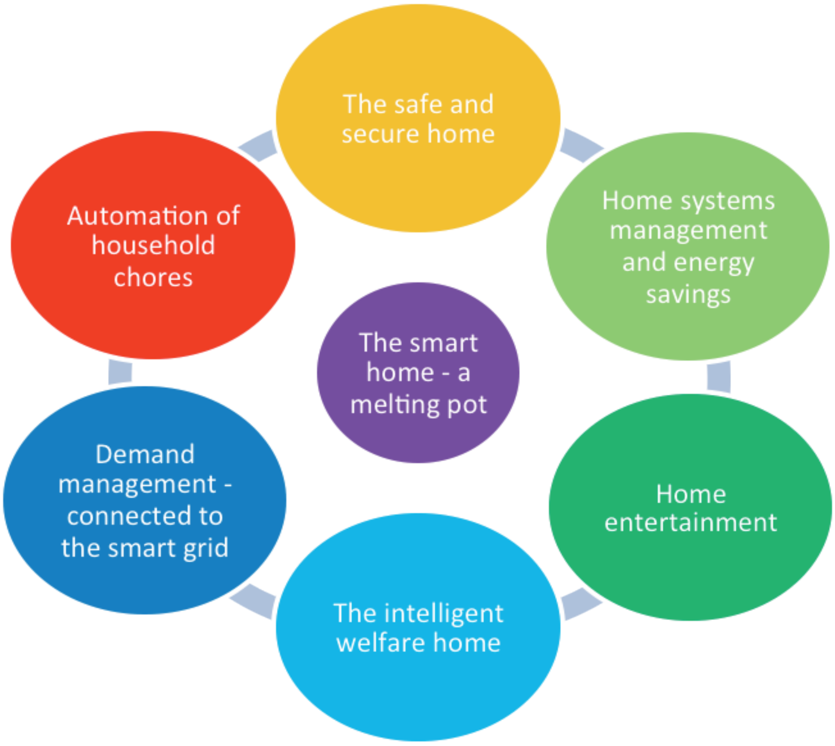


*Figure 1. The melting pot of the smart home.*

gateway, which also provides internet access to the home; and sometimes a server is used to organize the household's collection of films, music, games and photos, which can then be accessed from various rooms in the house.

*The intelligent welfare home (health and care)*: ICTs are also applied in the development of equipment for physically disabled, and smart home installations form part of this trend. Examples of early smart home installations include remote controls (eventually voice-managed) for opening and closing windows and doors, drawing curtains, turning lights and music centers off and on, and lifting and lowering kitchen tables (Bendixen, Christiansen 1999). Internet connection opens new opportunities for taking care of people with ill health in their homes, for instance, by monitoring various health indicators such as blood sugar level at a distance, or giving advice on treatment of wounds on the basis of transmitted photos. Telemedicine and the intelligent welfare home will no doubt gain ground with the increasing financial pressure on the welfare state.

The smart home in the smart grid will add a new ingredient to this melting pot when demand management is enabled through household connection to the smart grid. When the possible outcomes of the transition processes related to the smart grid are considered, it is important to keep in mind that the various ingredients co-evolve and that this co-evolution influences the overall energy impacts of the transition.

## Visions of a low carbon energy system and a smart grid

In 2050, the Danish energy system can be based 100 percent on renewables – mainly wind power, backed up by biomass – and electricity should be central to the energy system, covering up to 70 percent of total energy consumption as opposed to 20 percent today (Klimakommissionen 2010). This is the core vision recently published by the Climate Commission, which the Danish government appointed in 2008 to figure out how Denmark could become completely independent of fossil fuels in the future.

Wind is the most abundant renewable energy source in Denmark, and at present, wind power is also considered to be and become the cheapest renewable energy source (Klimakommissionen 2010: 36). Wind delivers its energy in the form of electricity, and the strong focus on exploiting wind energy implies that electricity will become the main energy form in the future energy system. Wind power can accordingly be used in the transport sector by electric vehicles (EVs), thus eliminating $CO_2$ emissions from gasoline. In heating of houses, electricity-driven heat pumps are to be used both in district heating systems and as replacement for oil burners in houses outside the district heating areas.

The commission report states, however, that a prerequisite for realising this vision is intelligent management of electricity consumption in households, institutions and companies – notably since electricity consumption is forecasted to be more than doubled by 2050.

Thus, some of the central challenges that a smart grid is to address are the following:

- Already today, Denmark has a relatively large share of wind energy in the system. Wind power cannot be stored effectively, so it has to be consumed when it is produced. The integration of fluctuating wind energy is facilitated by trading electricity with Germany and through the Nordic electricity market, Nord Pool. Here excess electricity can be sold when wind energy is abundant, and electricity from Norwegian and Swedish hydropower can be bought in calm periods.

Although this international trading is useful, it is not always beneficial in a socio-economic perspective, because electricity prices are sometimes very low when wind energy is plentiful. Recently, Nord Pool even introduced negative prices, which means that Danish electric companies have to pay to get rid of their excess energy. Therefore, increased integration of wind energy should be combined with increased use of the energy within the Danish borders, also in periods with heavy wind (Ea Energy Analyses, Risø DTU 2009). This forms the point of departure for the following issues.

- The increased national demand for wind-based electricity is expected to come particularly from transport and heating. The integration of electric vehicles and heat pumps, however, can enhance the classical problem with peak demand. Already today, peak demand resulting from two-three hours intense electricity use after working hours (e.g. from cooking dinner) means a very uneconomical energy production. This compels electric companies to have a lot of reserve power available, which means turning on entire power plants for a few hours high demand, and this is expensive.
- Furthermore, increased peak demand will cause a capacity problem in the distribution grid, because the cables are not rated for the much larger peaks anticipated as a result of the uptake of EVs and heat pumps. This means that the electricity grid should either be strengthened, which is traditionally done by building out with more and larger cables, *or* electricity demand – e.g. charging of EVs – should be managed intelligently to avoid large peak demands that would overload the system. The latter option is from a national economic viewpoint more attractive, since it requires less investment in reinforcements of the grid and also has other positive advantages:
- In addition to the avoidance of peaks that would strain the distribution grid, intelligent management of demand is also needed to ensure an effective utilization of wind power. Through demand management, it is possible to increase consumption when the wind blows and electricity is cheap, and to reduce consumption in calm periods. Intelligent management can also facilitate the integration and use of various storage technologies.
- A particular problem related to the integration of quickly fluctuating energy sources concerns the balancing of the grid and the avoidance of sudden drops in frequency. Smart grid investments offer possibilities for better surveillance of the frequency and voltage level in the grid and a better instantaneous regulation to avoid power outages. The costs of providing regulatory power, reserves and system services can also be reduced by letting more actors, such as local energy producers and households, participate in the provision of these services.

The main challenge is to balance consumption and production in the grid, and the basic architecture should thus consist of a combination of a power exchange highway and a data exchange highway, which enable the necessary real time dynamic feedback and interaction between e.g. households and energy producers. The smart grid has many definitions, but it can basically be understood as "the infrastructure connecting energy demand and supply using the latest developments in digital technology and communication technology in order to increase efficiency, reliability and security of the system" (Ea Energy Analyses 2010:21).

According to a report recently published by Energinet.dk (a non-profit enterprise owned by the Danish Ministry of Climate and Energy that manages the transmission net) and Dansk Energi (the Danish Energy Association), wind turbines will be able to cover 50 percent of the yearly Danish electricity consumption by 2025 (Energinet.dk, Dansk Energi 2010). By that time, Danes are expected to have 600,000 electric or plug-in hybrid cars and 300,000 heat pumps. As mentioned above, increasing electricity demand requires either a traditional expansion of the electricity grid or investment in building a smart grid. The economic benefit of choosing the smart grid solution is estimated to 6.1 billion DKK. In the analysis, the timeframe for the Danish transition is imagined in three phases, with a facilitation phase from 2010-2012 (e.g. mobilization of relevant actors, agreement on standards), an establishing phase from 2013-2020 (e.g. development of foundational platform/infrastructure), and a commercialization phase from 2021 onwards (refinement and expansion of smart grid services and solutions).

The smart grid solution with demand management differs from the present situation in which consumers are 'passive' or un-dynamic end-receivers of electricity, and where the load is adjusted according to their consumption practices and patterns. A smart grid is thus presented as both a more efficient and inexpensive solution to the challenges presented above (Energinet.dk, Dansk Energi 2010).

This vision enjoys support from a broad political spectrum in Denmark, from industry and NGOs. One of the arguments often brought to the fore and agreed upon by most actors is that Denmark stands a good chance of positioning itself at the forefront of the competition to develop smart grid technologies and should seize this opportunity. Certainly, many other countries share this idea of having a competitive advantage in smart grid development, relying on various positions of strength, but Denmark is already in the lead when it comes to 'green tech' solutions and particularly integrating wind energy in the electricity grid. The Danish electricity grid is well functioning and in many ways already intelligent. It has undergone a development from 15 central power stations in 1980 to a system consisting today of thousands of larger and smaller power-producing units, such as larger and smaller wind turbines and local combined heat and power plants.

Although most actors agree that wind and biomass are the two main renewables to rely on, there are some 'dissenting voices' as to the relative amount of biomass. The special-interest organization Danish Agriculture & Food Council has recently argued for a complete stop in the building of more offshore wind turbines until 2025 and instead suggests a huge expansion of the production of biogas, biomass and bioethanol – a vision that does not support the focus on an electricity-based energy system with heat pumps and EVs that is at the core of the smart grid vision.

Realising the smart grid vision is a complicated task that requires close cooperation and coordination between the different private and public actors and stakeholders. The smart grid vision still faces huge challenges in developing the ICT that can create dynamic interaction between the electricity system and consumers through monitoring, measurement, control and automation in the grid and at end-users, not to mention creation of new markets and institutional structures. This task requires that "choices are made that make sure that all actors are pulling in the same direction to avoid investments in and expenses for equipment and systems that will not be used optimally" (Energinet.dk, Dansk Energi 2010:5).

Although core actors do come a long way in aligning visions and do indeed aim to "mobilize promises about new technologies" (Pollock, Williams 2010:526), there are still some central disagreements on a very basic level. These include discussions about:

- The discourse on growth, which is important for the size of the challenge. Different emphasis is laid upon the importance of promoting energy savings in the vision, besides harvesting the other positive effects related to the management of peak loads and the effective utilization of wind energy. The right to increased growth and comfort is often presented as untouchable, e.g. that mobility should continue to grow (e.g. EVs as the family's second car). Could other less energy-demanding transport systems be advanced? The energy plans of various NGOs are relatively more focused on energy savings and changes in e.g. mobility systems.
- How much import of biomass? The available amount of biomass to back up wind energy is limited unless import from other countries is considered. The Climate Commission points out that biomass is becoming a scarce resource globally. NGOs are also arguing that the use of biomass should be restricted, because it will be competing with food production on a global level. The electric companies, however, have been arguing for import of biomass, because it extends the lifetime of their power plants, and Dansk Energi is against 'isolationism' and nationalism with regard to the biomass market.
- The relative priority given to large investments in transnational transmission cables and large investments in a national smart grid development. A thorough and dynamic connection to the European Super Grid enable a free flow of electricity between countries and take advantage of the synergies between the different national renewables – such as wind in Denmark and water in Norway. Energinet.dk is presently investing in transnational transmission cables. However, some actors argue that extended trade with other countries may result in higher and less fluctuating electricity prices and this will remove the incentive to invest in developing smart grid technologies. Others argue that they support each other and that under all circumstances, connection to the super grid is important since flexible demand and storage capacity are only relevant for a period of a few days. If the wind does not blow for weeks, the super grid is a necessity.
- Disagreements regarding the specific design of the energy system. The extent of district heating is not entirely agreed upon. The smart grid vision promotes introducing and expanding the use of heat pumps in relatively large areas, whereas the district heating sector argues for an investment in and expansion of district heating supplied by heat pumps outside these areas (Dyrelund, Lund 2010). District heating already functions well in Denmark and can exploit garbage combustion and contribute to the storage of wind energy in hot water tanks. As wind energy can be stored cheaply as heat in the district heating system, some actors emphasize the resulting lesser need for investing hugely in balancing production and consumption via the large transnational cables. The district heating system can also be developed in synergy with solar heat and geothermic energy, which would reduce the pressure on biomass resources.

Having presented the visions and discussions pertaining to the smart grid, we now turn to an investigation of the role households are thought to play in the future smart grid.

## The smart home in the smart grid – an introduction

Households are to become a core component in the smart grid in the role of dynamic partners that support the energy system by e.g. being flexible in their consumption and able to store – or even produce – electricity that can be useful for the smart grid system. Their role will thus change profoundly as they change from being viewed as a load to becoming collaborators – or at least willing to enrol in a shared, interactive network.

The household's more specific roles will obviously depend, however, on the more precise implementation of the vision: e.g. what technologies become dominant; should the households become more or less engaged in the collaboration; what emphasis is laid on energy savings and so on. For the sake of simplicity, we first summarize in a short overview the many roles that households can play from a technical perspective, some of which we have already mentioned.

- The shift to renewable wind energy means that the dominant energy form will have to become electricity, which should also become the dominant energy source within the transport and heating sectors. To replace fossil energy with wind energy in the transport sector, a large share of households need to replace gasoline-driven cars with EVs or plug-in hybrid cars. Likewise, to replace fossil energy with wind energy for heating, households outside the district heating areas would have to install electricity-driven heat pumps.
- To smooth out the traditional peak loads and avoid that EVs and heat pumps add to the problem, the households would sometimes have to displace their electricity consumption to other times of the day. Moving electricity consumption over time is also relevant in order to take advantage of wind power at night or a particularly large electricity production when the there is much wind. This time shift in electricity consumption can be exercised in several ways:
    a. Activities – such as washing clothes – can be done at times of the day when excess wind can be utilized, e.g. at night, or outside peak demand hours.
    b. Additionally, some appliances can store energy for later use of the appliance itself, e.g. when there is no wind: e.g. the battery in EVs, heat pumps with storage, or

freezers that can use electricity to drop some extra minus degrees, which can compensate for periods with no electricity and thus rising temperature.

c. Moreover, some equipment can store energy that cannot only be utilized by the device or appliance itself, but can also be delivered back to the smart grid system as electricity during periods with little wind and/or high demand. The battery in EVs is an example, but as this wears out the battery, it does not seem the most relevant option in the nearest future.

- An electricity system based on wind can cause sudden drops in frequency in the grid, e.g. if the wind direction changes. To reduce this problem, households can contribute with 'regulating power': brief decoupling of appliances to prevent blackouts. This demands automation, since it needs to happen within seconds. Several appliances could contribute, such as freezers, refrigerators, washing machines, dryers, mobile and laptop chargers etc.
- Households can also play a role in saving energy and in this way minimize the challenge of transforming the energy system. Automated energy-saving solutions that e.g. reduce stand-by consumption are seen as important smart grid technologies, but visualization of consumption is also part of the smart home. A central smart grid technology is the smart meter, which besides being able to provide readings and two-way communication between households and the electric company, can also visualize electricity consumption. Being able to register electricity consumption with an appliance-specific breakdown and visualize it, the smart meter is supposed to help households saving energy (cf. above, 'The smart grid in a historical perspective').
- Finally, households can play a role by being energy producers that cover their own needs, and to some extent, the needs of others. The smart grid can allow households to send electricity back to the grid and contribute to the production of energy. Different options exist to produce electricity, such as photovoltaics, wind, and micro CHP. Other forms of micro-generation that do not produce electricity for the grid but energy for the households' own consumption include e.g. solar heat and geothermal energy. The development of active houses and micro-generation seem to be happening faster in other EU countries such as Germany and Austria. Energy production can also occur in different forms of local collaboration between households, small local industry etc.

## The smart home – issues and discourses

### THE DIVISION OF LABOUR – THE CONSUMER AS ACTIVE CO-MANAGER OR UTILITY DEMAND MANAGEMENT?

One of the core issues among the stakeholders with regard to the role of households in the smart grid is the question of who should manage consumption in order to provide flexibility – the consumers themselves, or the electric companies. At each end of a continuum, the core idea is that households either move their electricity consumption themselves, based on two-way communication – through e.g. a smart meter, visualization and economic incentives, such as real-time pricing – or they allow electric companies to manage their electricity consumption and household devices from a distance based on certain criteria.

Central to this division is whether the smart grid technologies should take part in visualizing energy consumption or in making it invisible – should people be expected to change practices, or should they 'feel' as little as possible and continue everyday life as usual? In other words, should the technologies "actively 'disengage' consumers from re-evaluating their comfort expectations and practices" (Strengers 2008:382).

An example of these concerns among the smart grid stakeholders as to the role of consumers is the project eFlex, which the largest utility company in Denmark, DONG Energy, is just embarking on. It aims to test how willing their customers are to be flexible in their energy consumption. They are searching for approximately 200 families that will be divided into three groups: one group with EVs, one group with heat pumps, and one group with neither. All the families are provided with a GreenWave Reality energy management system, i.e. a home gateway, and for the first two groups of families, DONG Energy has applied their own software to the GreenWave Reality system to enable demand management. DONG Energy will be able to charge the EVs and run the heat pumps, when it is suitable for the smart grid system, but the customers will be able to choose certain profiles or criteria DONG Energy can operate within. These include specific temperature ranges in the house that they are willing to accept, or certain times the EV should always be fully charged. In return, the customers are given the management system as well as an iPod to support the interface. They can also choose between receiving cheap electricity or always 'green' electricity – i.e. from wind. The third group of families can manage their own consumption and appliances through the energy system, which also provides them with detailed information on their appliance-specific consumption patterns. They are priced on an hourly basis with dynamic prices.[1]

In this way, DONG Energy is investigating, on the one hand, flexibility in demand management, and on the other, the potentials that lie in motivating people to move energy consumption themselves through dynamic pricing and feedback. The project will also illuminate another point that we elaborate on later, namely whether managing other appliances in the home besides EVs and heat pumps presents any real flexibility for the smart grid system. Put another way, they want to assess how large the 'displacement potential' of electricity consumption from smaller appliances in the home is (e.g., freezers, washing machines, chargers etc), and whether investing in the necessary communication infrastructure in the home to enable this can pay off. The potentials of managing home appliances, however, will be investigated much more thoroughly in the far larger, newly established smart grid platform iPower, which involves 10 universities and 16 companies. The project will utilize experiences from the smart home demonstration project, Energy Flex House,[2] and the test facility PowerLabDK at Risø DTU.

1. http://www.dongenergy.dk/privat/Kundeservice/kontakt_os/Pages/Vildutest-evoresnyeprodukt.aspx and interviews with DONG Energy managers.

2. The Energy Flex House is a collaboration between the Danish Technological Institute and a large number of Danish companies. It consists of two houses, one technical laboratory facility and one house inhabited by a family.

Large-scale testing of flexible demand in households is expected to be done through the project EcoGrid EU, which is the largest European real-life, full-scale testing of a smart grid so far. It is planned to commence in spring 2011 on the Danish island of Bornholm.[3] The project will integrate at least 2,600 households, which will participate with flexible consumption as a reaction to real-time price signals. Thus, the project will develop a real-time market concept to give small end-users – e.g. households and local producers – the possibility to offer transmission system operators balancing and system services in the grid. The flexible demand potentials of EVs may also be investigated through cooperation with the EDISON project.[4]

Both ways of approaching the role of the households in the smart grid enhance the use of green energy and make energy consumption more energy efficient, but the aim of letting consumers manage energy themselves and be confronted with their consumption also aims to make households more aware of their consumer behaviour and accordingly motivate them to save energy.

However, as shown in Figure 1, energy savings through home systems have been part of the smart home 'melting pot' for quite some time without really providing the result hoped for. Several trials with consumers show that any behavioural changes accomplished through e.g. feedback and visualization on displays are not permanent and that people return to their old consumption patterns after a period of about three months – regardless of the continued feedback. One suggested explanation is that the amount of money to be saved on the electricity bill is too small to motivate a permanent break with everyday life habits. Therefore, the customer should not be bothered with the hassle of engaging in the smart grid system; instead, technological automation and utility control should automate the changes and allow consumers to continue the same convenience levels and with the same habits as before.

As mentioned above, the division of labour between the households and utilities is not necessarily envisioned as black and white – an either-or situation. Rather, a multitude of ways in between could be developed to utilize both demand response, automation technologies, and consumer engagement. For example, the electronics and software company Develco and their collaborators have developed a washing machine control unit for the newly finished project, 'Minimum Configuration Home Automation' (MCHA).[5] An important part of the project was to develop and test new methods for user-driven innovation of energy management technologies. The unit – a display – communicates with the smart grid and basically consists of a green, yellow and red button, which give the consumers the possibility to programme the washing machine to start within the next 24 hours, whenever electricity is 'greenest', (green), when it is cheapest (yellow) or right away (red). The relative importance of such a solution as part of the smart grid visions is unclear, but it does seem that most of the actors in the electricity sector focus on a model or a vision in which they sign a demand-management contract with households, and in this context, the MCHA device is of less importance.

The concepts of visualization of consumption and the energy-aware consumer ideal are still very strong among many stakeholders, however, and continue to be mentioned as an element in the visions. The Danish Energy Savings Trust is especially attentive to also keeping the smart grid discourse on energy savings and conscious consumption, instead of making it purely a question of handling increased electricity consumption, spreading out of peak loads, and the integration of fluctuating renewables.

#### ECONOMIC INCENTIVES FOR DEMAND MANAGEMENT

Regardless of the precise distribution of roles between the households and electricity suppliers, moving demand necessitates a change in the tax and tariff structure of the electricity market that moves towards dynamic tariffs and taxes. Today, the spot price of electricity is only approximately 20 percent of the total price paid by consumers for their electricity, whereas taxes to the government and tariffs for electricity transmission amount to around 80 percent.

Taxes and tariffs are fixed, however, which means that even though customers are charged on an hourly basis and offered dynamic spot prices – and they can utilize this dynamism through ICT (e.g. a smart meter or home gateway) – the varying spot prices have little influence on the total price per kWh and result in very limited total savings. The incentive is thus small for suppliers to utilize and develop smart grid technologies and the motivation little for consumers to move consumption, unless they are large-scale customers or have both a heat pump and an EV.

It is therefore suggested that tariffs reflect the actual costs to the system of increased consumption at any given time. A working group on dynamic tariffs, led by the Danish Energy Agency, published a report in June 2010 that concludes that these changes in tariff structure are foundational to development of smart grids in Denmark (Energistyrelsen 2010).

Surprisingly, the Danish Ministry of Taxation published a report just before, which concluded that there would be no arguments for implementing smart grids in Denmark, since the nature of wind patterns do not interact well with possibilities of shorter displacements of consumption through household heat pumps and EVs (Skatteministeriet 2010). Therefore, the report also rejects the idea of dynamic taxes. The ministry has suggested, however, that the high taxes on electricity should be lowered for electricity used for heating to match the lower taxes on oil and gas. These tax cuts would not drain the treasury, since they also promote enhanced electricity consumption. The tax reduction should also include electricity-consuming radiators.

According to the report, the excess wind turbine electricity should instead be utilized in the district heating system. A new law passed in 2009 allows the district heating sector to utilize electricity to heat water tanks with electric boilers and heat pumps.

#### HOUSEHOLDS AS INVESTORS

A scenario with a family living in a smart home with an EV and heat pump, as well as various appliances such as a freezer, refrigerator and washing machine, which are also connected

3. The Danish partners in the EcoGrid EU project are Energinet.dk, Østkraft and DTU. Http://www.ens.dk/da-dk/info/nyheder/temaer/fremtidensenergisystem/sider/20100219temabornholm.aspx

4. The partners in the Edison project are The Danish Energy Association, DONG Energy, DTU, Østkraft, Eurisco, IBM and Siemens. The project aims to develop an intelligent infrastructure for EVs. http://www.edison-net.dk/

5. The MCHA-project is a collaboration between the Engineering College of Aarhus, the Alexandra Institute, Develco Products and Seluxit.

to the grid to enable demand management, requires relatively large investments to be made, both by households and the electricity suppliers, which could be expected to pay for parts of the ICT infrastructure as well as smart meters.

At the moment, however, some actors are arguing that what can be achieved from integrating household appliances – such as white goods and mobile and laptop chargers – into the smart grid, would provide a very small potential for flexible demand and economic savings, and that the necessary investment would not correspond to the potentials for displacement of demand, storage capacity, or regulation power.

The potentials for large electricity consumption, and thus large flexibility, lie in heating and transport. However, an earth-to-water heat pump is quite an expensive investment for a household, and the potentials for receiving a return on the investment seem relatively small at the moment. Of course, the return increases when energy prices go up, but in the meantime public subsidies may be needed. Just relying on price fluctuations on electricity to motivate such an investment may not work, because the fluctuations will be very small most of the time, only interrupted by very short periods with highly fluctuating prices (Wilke 2010).

A change in the taxation of electricity for heat, as argued above, could increase the incentive to invest in heat pumps. Since March 2010, the government has provided subsidies for households that replace their oil burner with a heat pump, and it has just prolonged the tax exemption on EVs in Denmark until 2015.

The market for heat pumps is still immature, though, and the energy efficiency and quality of the heat pumps on the market varies greatly. Danish Energy Agency has, however, made a list of energy-labeled heat pumps to guide consumers.

A big concern regarding the will to invest in smart home devices for households is also the lack of standards for just about all technologies pertaining to the smart grid. The missing standards for e.g. wireless technologies or EV charging plugs leaves consumers with many questions as to the durability of the product they are buying. Most consumers hesitate to invest in an entire smart home solution based on the zigbee wireless communication protocol; it could become obsolete in five years and be replaced by e.g. z-wave or another communication form entirely, such as the already established copper wires, wi-fi etc. However, many stakeholders are presently working for open standards.

#### CONSUMER CONCERNS ON PRIVACY AND SECURITY

Stakeholders are beginning to realize that in the eagerness to develop functioning smart grid technologies and systems, questions of privacy and cyber security are often forgotten. In the last few years, several comprehensive reports analyzing the security issues of the smart grid and the smart home have been produced (e.g. in USA) that warn about severe hacking risks and terror issues. Danish stakeholders such as Dansk Standard, and the white paper "Intelligent Energy System. A White Paper with Danish Perspectives" (Ea Energy Analyses 2010), also point to the potential internal and external security and hacking issues of the smart grid. However, these are issues that can be addressed in several ways. A core unit that could be vulnerable to hacking is the smart meter, which functions as the gateway between the many digital units inside the house and the exterior world. Traditionally, the smart meter has been envisioned as the unit that is to handle all dynamic two-way communication between the household and the smart grid – electricity suppliers, Nord Pool etc. However, leaving only traditional one-way meter reading of electricity to the electricity meter and instead introduce the 'home gateway' as another information hub, which can handle all communication to appliances in the household – the meter, the local energy production, and the energy network operator (Ea Energy Analyses 2010: 57) – reduces the number of exposed access points for hacking. Communication through the smart meter electricity wires may also be too slow for some of the features and services that are envisioned. Other stakeholders are calling for another solution where instead of one home gateway in the house, there are several digital ports to the household with IP addresses, thus enabling more flexible 'plug-and play' solutions for the customers. This enables a combination of products from different companies.

Another concern for households and consumers relates to the vast amount of person-sensitive digital data that a smart grid system produces. Consumer organizations are raising concerns about privacy issues and the fact that explicit data about electricity consumption and the knowledge they reveal about everyday habits can be misused by criminals or insurance companies. Information that no one is home or about sudden increases in electricity consumption – allegedly an indication of the acquisition of new commodities, appliances etc. – could be valuable to them.

A final concern proposed by actors engaged in smart grid development relates to the ownership of the data produced. Do the households own their data, do the suppliers, or do the home gateway software companies? These questions are relevant, e.g. for the retail market, in case a customer wants to shift supplier and needs to move the information generated to the new provider (Ea Energy Analyses 2010: 58).

### Perspectives and implications for energy consumption

In the following, we present some of the discussions we find interesting in relation to the smart home in the smart grid and the perspectives for energy consumption.

As we write in the historical section, when investigating the possible outcomes of the present smart grid transition process, we need to keep in mind that the smart home is a melting pot with a long history of different trends and ideas. Our contention is that these different ingredients of the melting pot co-evolve and that this co-evolution will have consequences for the overall energy impact of the transition. In this section, we only deal with relatively narrow issues of co-evolution, where the smart grid aspects of the smart home directly cut across other aspects of the smart home. A deeper analysis would have to include the dynamics related to broader societal issues, such as the strong forces behind the development of the intelligent welfare home.

#### WHAT IS CO-EVOLUTION?

The co-evolution of trends in the smart home is not new, but has been going on especially since the 1980s, when the visions of the smart home, such as intelligent automation of household chores, gained ground. These ideas have later co-developed with home entertainment, the safe and secure home and home systems management, and energy savings. An example is the 'Electronic Housekeeper', which is a home automation console developed in Denmark in 2006. Via a touch screen, it is possible for the consumer to manage all electrical appliances in the household and visualize their electricity consumption through an appliance-specific breakdown. They can e.g. programme the console to switch off all electrical appliances when they leave the house, thus eliminating stand-by consumption, or they can programme the console to automatically enter a 'night' condition with lower temperature. Most of the buttons on the touch screen, however, have to do with possibilities to watch TV, listen to music, receive food recipes and suggestions for the best nightlife nearby, or send an alarm by sms in case of burglary.

Another example of co-evolution is the GreenWave Reality energy management system, which consists of energy management and an electricity consumption display, but also advertises for other services that could be provided to add more value to the investment. These relate to the intelligent welfare home and security, as is apparent on the GreenWave Reality website: "Our open-standards approach also provides the platform with the flexibility to incorporate future services such as home security and elderly care."[6]

The next step in the evolution comes when the home energy management system is offered in combination with demand management and connection to the smart grid. This is the case with the eFlex demonstration project, which also offers an iPod to support the management system, possibly also when away from home if wifi is accessible. An iPod has many integrated entertainment features, such as games and music, and it therefore supports the co-evolution of entertainment and demand management.

#### DRIVERS FOR CO-EVOLUTION

Presenting a comprehensive analysis of the drivers of the past and present co-evolution transgresses the limits of the present paper. However, some analysis can be made of the reasons for the present co-evolution.

Some of the actors eager to promote smart grid in Denmark are attentive to the difficulties that can arise in persuading consumers to play their role in the smart grid – among other reasons, due to the limited economic potential per household and the investment that has to be made in a communication infrastructure. They accordingly suggest that demand management and home energy systems in households are offered as part of other services that the consumer is willing to pay for –notably within entertainment, health, security, comfort or convenience. Parallel to the concept of 'greenwashing', this trend could be characterized as *'funwashing'*: just as or instance ICT companies try to 'greenwash' their products by arguing that they can save energy even though their main function relates to entertainment, electricity companies may try to persuade consumers to buy their 'boring' management products by bundling them with more attractive features.

Thus, as compensation for allowing electric companies to manage household electricity demand, consumers can be offered a home gateway with features like those mentioned above. They may also be offered an 'electricity subscription', which is a package of all different kinds of services and products in addition to cheaper or greener electricity. These could be an extra mobile phone to support the remote interface of the gateway – or an iPod as mentioned in the case of the eFlex project – surveillance and home security benefits such as an sms in case of burglary, convenience elements such as a preheated and pre-lit house when coming home from work, or more exotic visions such as automated plant watering or pet feeding. These extra services may also be provided by other commercial actors such as insurance companies. The expectations to commercial actors are somewhat similar to the expectations to content providers on the internet – provide a platform and someone will fill it out.

Potentially, entirely new commercial actors will enter the court, or old ones will merge, to develop new services, products and alliances. For example, EV manufacturers could offer an advantageous 'electricity subscription' to follow the acquisition of a new EV, which includes software to support entertainment, convenience, or security, such as logging driving milage or sms in case of theft etc. Or electricity suppliers could potentially move into selling EVs together with an electricity subscription. Many stakeholders compare this dynamic to what happened in the telecom industry when mobile phones replaced old landline telephones and there was an explosion of new types of subscriptions. For example, free texting and music services were offered for a fixed monthly amount, together with acquisition of a mobile phone.

#### CONSEQUENCES OF CO-EVOLUTION – IS THE SMART HOME A TROJAN HORSE?

As evident from the previous sections, the present co-evolution of energy management is likely to introduce more electronic equipment into the household, and they also consume electricity. Together with indirect energy consumption, the amount of energy necessary to produce and run, not only wireless technologies such as radio transmitters to be installed in all appliances, but also smart meters and home gateways as well as extra displays and mobile phones, will undoubtedly amount to something – besides depleting natural resources.

Even though the smart home electronic devices are not costly in terms of electricity consumption compared to their potential for demand management and savings, they may become part of an unsustainable development at a much more basic level. Previous studies have shown that the integration of ICT in household practices has contributed considerably to the increase in residential electricity consumption (IEA 2009, Røpke et al. 2010). In the Danish case, residential electricity consumption would have fallen in recent years without the growth in ICT: from 2000 to 2007, electricity consumption for non-ICT fell by nearly 10 percent, while electricity consumption for ICT increased by 135 percent. Part of the background is the ongoing integration of ICT into all sorts of everyday practices – also in domains where the use of ICT is less obvious, like do-it-yourself, sports and recreational activities. In addition, the integration of ICT is often accompanied by a diversification of practices. Watching television can now be done both on a TV and on the internet (Jensen et al. 2009) – a trend which may also add to direct and indirect energy consumption. The development of the smart grid and the related installations

6. http://www.greenwavereality.com/solutions/

and functionalities in the home may intensify these trends, encouraging even more integration of ICT into such practices as cooking, laundering, driving and cleaning. Although smart functions may be applied to achieve energy savings, they are also open to attending to other concerns, which may increase energy consumption.

The introduction of smart grid and smart home technologies may furthermore have the potential of creating both entirely new practices and also normalizing new expectations to comfort, convenience, entertainment, security, health care and so on. An interesting example is an ongoing Danish study of heat pumps and their ability to function also as air conditioners. There is no tradition for using air-conditioning in Danish households. However, the introduction of heat pumps in relation to the rollout of smart grids, which also have the functionality of air conditioning, may create a new household practice of cooling and new normal expectations to indoor summer temperature, and hence end up increasing energy consumption.

Contra the intentions of moving toward more sustainable consumption, the smart grid could thus support the creation of entirely new energy-demanding practices and change consumption dynamics. Smart home technologies can in effect become a dynamic that normalizes new energy-demanding practices and supports the construction of new normal expectations to comfort and convenience, entertainment, security and health care. Expectations that could be escalating (Shove 2003).

Another aspect of the normalization of higher levels of comfort is the possible construction of new normal expectations as a consequence of the demand management trials that are presently being planned in Denmark, such as the eFlex project or the 'From Wind Power to Heat Pumps'[7] project. A previous study (Strengers 2008) has argued that the demand management trials being delivered by the utilities are shaping, and being shaped by, normal expectations of comfort. When setting up criteria within which the utilities need to operate in order to achieve demand flexibility – such as a specific temperature range that consumers are assumed to accept as comfortable – this can normalize household temperatures that are actually higher (or lower during summer if the heat pump functions as an air conditioner) than would have been the case if the household were not involved in a demand management agreement with their utility company. It does not seem that any attention is given to these possible dynamics in the present development. Investigating the assumptions of the managers who design the trials in the utility companies, and the impact the demand management trials have in relation to escalating comfort expectations (Strengers 2008) is relevant in the present transition.

### PASSIVE CONSUMERS OR ENGAGED CITIZENS – HOW WILL THE TRANSITION COME ABOUT?

Denmark has today a thriving wind turbine industry. The history of this development may raise another discussion that we only open in the present paper. It is a hallmark for the development of wind energy in Denmark that it was carried by public engagement in the late 1970s, partly due to the opposition to nuclear power production. Until the 1990s, most wind turbines were produced by smaller machine manufacturers and owned by local wind turbine guilds.

The visions in the present transition of the energy system is dominated by an idea that consumers should not notice the transition they are to become a part of. The assumption in the Danish debate among stakeholders is that households can be engaged as passive consumers who react to economic incentives. The visions about the role of households primarily involves a discussion of how we should develop a combination of complex technologies and a market with a pricing system that supports the right consumer choices. But the transition of the energy system may be such a great challenge that it requires a more active engagement that extends beyond the traditional consumer role. Some very ambitious local energy projects, like the one on the island of Samsø, illustrate how much a community can achieve when local entrepreneurs succeed in mobilising citizens for a common goal. As Späth and Rohracher (Späth, Rohracher 2010) emphasize, local processes can be successful when they are guided by a vision and combine the energy perspective with other core concerns, such as saving a region from economic decay. Such examples may inspire the mobilization of citizens in transforming the energy system, also at the national level.

The magnitude of the present transition could also be a good opportunity to question more fundamental assumptions regarding the way our society works, and whether elements should be structured entirely differently. As Anthony Giddens pleaded at the World Climate Solutions conference in Copenhagen in September 2010, addressing climate change, energy and consumption issues is not only a question of developing the right technologies; we also need sociological innovation and creativity. Maybe we should not only focus, for example, on developing EVs that give us better versions of the old transport system; maybe we should start thinking 'beyond the car'.

## Perspectives for further research

In this paper, we have suggested that the smart home in the smart grid will co-develop with the other ingredients of the smart home melting pot, and that this co-development may have negative consequences for total energy consumption. However, we have only opened the discussion in this paper; much more work should be done in this area. For instance, more research is needed to explore further the possibly contradicting interests between smart home stakeholders in the present transition. Also the different emphasis on energy savings and flexible demand , respectively, could be investigated more systematically. This could for example be done by analyzing the discourse on passive and active houses vs. smart homes.

User conceptions among the core actors – such as planners and managers of user trials of demand management – in the energy sector or the IT sector should also be surveyed. As discussed previously, they may play an important role in creating norms for convenience, comfort and entertainment in the smart grid. We do not have the impression that this issue receives much attention in relation to the possible implications for sustainable energy consumption in Denmark.

7. From Wind Power to Heat Pumps is a collaboration between Energinet.dk, Nordjysk Elhandel A/S, SydEnergi and NeoGrid Technologies, among others. The project aims to demonstrate how 300 households with heat pumps can be interconnected to provide storage power for wind turbine energy. It will also test the consumer flexibility.

In general, consumers as study objects in the case of the smart grid are highly relevant and under-studied. Therefore, we find it relevant to study, for example, how the smart home and its different aspects – such as remote demand management, heat pumps, EVs – interact with everyday practices in households.

As touched upon in the previous section, the active role that domestic actors can play in transitions such as the present transformation of the energy system, with few exceptions (Nye et al. 2010), has not been thoroughly investigated. It would be interesting to analyze, along the lines of the discussion of energy savings and consumer engagement, the far more active role consumers – or citizens – could possibly play in *constructing visions* (that are presently dominantly articulated by actors in e.g. the energy sector) or negotiating how we should consume and produce energy sustainably in the future.

It has been beyond the scope of the present paper to assess the role consumers play in developing the smart grid visions, although we have mentioned cases of user-driven innovation of smart grid technologies through the MCHA project and eFlex. However, one way of mobilizing consumers in this transition may be to include them, not only in the development of sustainable technologies, but also in the creation of visions for the future through user-oriented future studies. Here, users, through exercises in a participatory process, could develop visions of a sustainable future. The "researchers can try to find out what the users actually want their life to be like in the future, and on the basis of this, derive the necessary technological solutions" (Heiskanen 2005: 101).

A last important object for further research concerning the active role of domestic actors relates to the points made above about local energy production, with focus on the design of the systems of provision – on local, decentralized production of energy versus non-transparency of production and consumption in large interconnected smart grids. As argued above, integrating renewable sources in the energy system in a local perspective could possibly have transformative powers that the present smart grid visions may not have. In other words, if energy production and consumption happens in local systems or communities, then households and local businesses could be more inclined to participate in and even become catalysts for the integration of renewables, even if it could mean a transformation of aspects of their lives. This is not to say that the sustainable transition possibilities in local production are only about the potential for creating mobilizing visions and desires; investigating local production also addresses how the specific system design may influence the consumption enabled by it.

What this indicates is that sustainable energy consumption and civic engagement are not just a question of the individual's attitude, behavior and choice or about efforts of 'persuading' the individual consumer to make a 'green' choice (Shove 2010), but they are also about the materiality and socio-technical dimension of life. As Shove argues, "certain forms of demand are unavoidably inscribed, for example, in the design and operation of electricity and water infrastructures and in the architecture of the home itself" (Shove 2010: 1278). In this view, social change involves not only individual attitudes but also technological artifacts and "new markets, user practices, regulations, infrastructures and cultural meanings" (Elzen et al. 2004: 1) that continuously interact and have agency. The way domestic actors interact with systems of provision and how these systems are configured have influence on our daily practices and energy consumption. Studying cases which could enlighten these considerations – e.g. cases of micro-generation in a local community as well as micro-generation in a smart grid system – could be interesting and possibly enrich or inform the present dominating visions of the smart home in the smart grid in addition to contributing to research communities concerned with renewable energy and local production.[8]

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8. See for example the conference, 'Changing the Energy System to Renewable Energy Self-Sufficiency', http://www.ress-conference.uni-freiburg.de/

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